ANL-FRA-169

Multigroup Calculations Using VIM: A User's Guide to ISOVIM

by R. N. Blomquist

Argonne National Laboratory, Argonne, Illinois 60439
operated by The University of Chicago
for the United States Department of Energy under Contract W-31-109-Eng-38

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September 1992

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by

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*Work supported by the U.S. Department of Energy, Nuclear Energy Programs

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ABSTRACT

This document describes the VIM multigroup capability, the procedures for generating multigroup cross sections for VIM, and their use. The multigroup cross section generating code, ISOVIM, is described, and benchmark testing is documented.

I. Introduction

Monte Carlo calculations have long been used to benchmark more approximate solution methods for reactor physics problems. The power of VIM (ref 1) lies partly in the detailed geometrical representations incorporating the (generally) curved surfaces of combinatorial geometry, and partly in the fine energy detail of pointwise cross sections which are independent of the neutron spectrum. When differences arise between Monte Carlo and deterministic calculations, the question arises, is the error in the multigroup cross sections, in the treatment of transport effects, or in the mesh-based treatment of space in the deterministic calculation? The answers may not be obvious, but may be identified by combining the exact geometry capability of VIM with the multigroup formalism. We can now run VIM in a multigroup mode by producing special VIM Material files which contain point-wise data describing multigroup data with histograms. This forces VIM to solve the multigroup problem with only three small code modifications. P_N scattering is simulated with the usual tabulated angular distributions with 20 equally-sized scattering angle cosine meshes.

The arrangement of data in VIM Material Files, and the processing steps are described in Section II. Section III describes how multigroup cross sections used in VIM can be checked with great precision. Section IV describes verification testing.

II. Multigroup VIM Material Files

The approach taken was to embed in the VIM material files all the multigroup data in such a way that the library processing procedure and codes are unchanged and that the VIM collision physics routines could be retained with minimal recoding. Figure 1 illustrates the process which produces multigroup VIM cross section libraries, which is quite similar to that used for the continuous-energy production libraries. The codes and procedures for continuous-energy library production are described elsewhere (Refs 2 and 3). The steps to produce a multigroup library are as follows:

(1) In the multigroup mode, the ASCII VIM Material Files (Ref 4, Appendix F), representing either individual nuclides or mixtures, file XSFT08(Ref 4, Appendix F), are either produced by hand according to the prescriptions described below, or preferably are converted from another form by the ISOVIM code documented here. If XSFT08 is hand-generated, the user must also generate the ASCII files, ISOVIM.F1FT05 (Ref. 4) and BAND05 (Appendix C of Ref. 4), carefully following the details as prescribed in Appendix E. These details are not obvious, nor are they intuitive, and since ISOVIM produces these files automatically, generation of cross sections by hand is not recommended. Hand-generated input should follow the CASMO edit format included in Appendix C.

(2) The ASCII data file, XSFT08, is then converted to a set of binary files using the VIM Material File editing and conversion code, XSEDIT (Ref. 4). The script, "get.binary" (listed in Appendix F) reads the list of VIM nuclide or material ID numbers from the ISOVIM output file, ISOVIM.F1FT05, prepares the appropriate XSEDIT control input ASCII files, XSFT05 (Appendix E), and executes XSEDIT as many times as necessary to convert XSFT08 to the set of binary VIM Material Files. Each binary file is name "Ixxxxxx", where "xxxxxx" is the 6-digit VIM Material ID number.

(3) The FILEONE and BANDIT ASCII input files produced by ISOVIM (ISOVIM.F1FT05 and ISOVIM.BAND05, respectively) must be renamed F1FT05 and BAND05.

(4) FILEONE (Ref. 4)is executed to accumulate material file size data in the binary file, FILE1, for subsequent use by BANDIT.

(5) BANDIT (Ref. 4) is then run to produce the data library read by VIM. BANDIT's intended purpose is to allow VIM calculations using very large continuous-energy libraries on memory-limited computers by

partitioning the nuclear data into at least two energy bands. Although multigroup libraries are probably not large enough to stretch memory limits, VIM can only read nuclear data libraries produced by BANDIT. The BAND05 prescription used by ISOVIM and described in Appendix E forces all the multigroup data into the upper energy band, leaving the lower of the two bands present as a vestige playing no part in the particle history simulation. This minimizes cross section I/O time.

The representation of multigroup cross sections in VIM Material Files is accomplished by writing these files according to a detailed prescription. This prescription is embedded in ISOVIM so that the details do not have to be mastered to use the multigroup capability, but it is provided in great detail for reference in Appendix A for those familiar with VIM Material File formats. A more general description of the multigroup representation, including the few modifications to VIM, follows here:

(1) Piecewise - constant distributions are used to describe all multigroup cross sections and the energy dependence of $\bar{\nu}$. The corresponding cross sections in the continuous energy VIM libraries are piecewise linear, and VIM interpolates these on the energy mesh using the linear - linear scheme. We represent the infinite derivatives in the multigroup histogram using the linear formalism by double-pointing, i.e., adding a second energy grid point at each energy boundary. The dependent variable at the first of the coincident energy points is the cross section or $\bar{\nu}$ of the energy group just above the grid point, and the second coincident energy point refers to the energy group just below the grid energy. This technique is applied to all energy grids and distributions. Since the tabulated $\bar{\nu}$ distributions in VIM are fixed-dimensioned to 40, one cannot produce cross sections with more than 20 groups without modifying the $\bar{\nu}$ table before running XSEDIT.

(2) Within-group scattering is simulated by elastic scatterings in which no energy is lost; accordingly, the mass number is set to a very large value. Records 12 and 13 can be used to describe tabulated anisotropic scattering angle distributions. Anisotropic scattering cross sections are assumed not to include the factor $(2\ell + 1)$. A problem may arise when a very anisotropic (high-order) angular distribution is represented by a lower-order P_n series. The resulting probability density function (pdf) can be negative over part of the scattering angle cosine domain. The scattering angle distribution is sampled by comparing a random number to the cumulative distribution function (cdf), which is the integral of the pdf. The cdf is monotonic for a non-negative probability density, but multivalued if the pdf contains negative values. When this occurs, it is impossible to sample part of the range, the wrong distribution will actually be sampled, and the Monte Carlo solution will differ from the deterministic result based on the same multigroup set. ISOVIM prints error messages when this happens.

(3) When all out-of-group scattering from a group is isotropic, one sums the out-of-group scattering cross sections for each group and stores the result as the inelastic continuum scattering cross section in the VIM material file. (In this context, group-to-group scattering includes upscatter, even though the nuclide continuous-energy VIM material files incorporate continuum inelastic scattering as epithermal neutron downscattering only). The secondary energy distributions, including upscatter, are then constructed as piecewise constant (again, double pointing) on record types 14, 15, and 16B. Since inelastic continuum scattering in VIM is isotropic, the angular distribution is automatically sampled correctly in VIM.

(4) If any out-of-group scattering from a group is anisotropic (usually for elastic downscatter), a modified inelastic level formalism is used in the VIM material file for all secondary groups in that

scattering matrix column, whether isotropic or not. One inelastic level represents each combination of incident and secondary energy groups. As with anisotropic elastic scattering, the scattering angle cosine distributions are described with one record type 12, and two records type 13, one at each end of the incident group series. (These distributions can also contain negative probabilities due to P_n series truncation.) The secondary energy distribution is included as a third record type 13 with a table energy equal to the bottom of the incident energy group, in which the secondary energy group boundaries are stored at the beginning of the angular distribution array. VIM was modified so that subroutine INELAS uses the secondary energy values when appropriate.

(5) VIM was modified so that subroutine CROSS searches the entire energy grid for the appropriate points if the multigroup form is involved; this is necessary to accommodate upscatter in the higher energy band.

(6) The group-to-group tallies in VIM are based on the assumption that inelastic scattering is P_o. All multigroup out-of-group scattering (including that which was elastic in an ISOTXS) file, is inelastic in VIM. In order to recover the anisotropy in the tallies, the inelastic multigroup out-of-group scattering is tallied as elastic scattering.

One drawback to the tabulated angular distributions used in VIM is the assumption that 20 uniform intervals of width $\Delta\mu = 0.1$ are fine enough to represent the real distribution. If the higher-order cross section estimates from VIM are significantly different from the ISOTXS values, and the low-order cross sections agree, then the tabulation errors may be significant.

Two samples of multigroup material files are listed in Appendix B, and a more complex example is in MVS data set \$B24366.VIM.MULTIGRP.DOC#RB01A.

In multigroup VIM calculations, one can either use isotopic material files in mixtures in exactly the same way as the ENDF/B-based VIM Material Files are used, or one can produce macroscopic material files, each of which describes a complete mixture. In this case, each mixture is treated in VIM as if it is a single isotope. BANDIT and VIM presently limit the total number of isotopes to 40, so if macroscopic files are produced, then only 40 mixtures are allowed.

Five methods have been used to produce multigroup VIM material files. Initially, several few-group benchmark problem cross section sets were generated by hand-typing the card-image VIM material files. Subsequently, P. J. Finck wrote a program to convert data from MC^2-2 printed output files, a capability not included in the present code. This program, ISOVIM, has been modified by S.C. Mo (Ref 5) and J.L. Vujic (Ref 6) to convert an ISOTXS (Ref 7), COMPXS (Ref 8), CASMO-3 (Ref 9), or CPM-2 (Ref 10) file to equivalent card-image VIM material files. At present, ISOVIM can convert cross section sets with up to 150 groups, with transport corrected P_0 cross sections. ISOVIM recomputes the within-group scattering cross section to preserve the total and capture cross section before transport correction. This ensures consistency, since VIM computes the capture cross section as the difference between the total cross section and the sum of the other reaction rates, instead of carrying capture explicitly in the VIM material files. Appendix C contains an ISOVIM input description, and Appendix D lists a sample deck.

To run multigroup VIM, the only input change is to set IOPTS(15) to 1.

III. Statistical Properties of Cross Section Edits

The relationships of the VIM tallies and their statistical properties to the physical quantities allow the user to check the principal cross sections in multigroup VIM material files quite thoroughly. The group flux in a region is, mathematically,

$$\phi_g = \int_V \int_{\Delta E_g} \phi\,(r,E)\,dV\,dE \tag{1}$$

where E is the energy group and V the region volume. In VIM, the group scalar flux is estimated by the average tally:

$$\phi_g \approx \frac{1}{N_B} \sum_{b=1}^{N_B} \frac{1}{N_H} \sum_{h=1}^{N_H} \sum_{e\in(h,g)}^{N_e(h,g)} w_e \int_{r_{e-1}}^{r_e} dr \tag{2}$$

Here, there are N_B batches (usually generations) of N_H histories each with $N_e\{h,g\}$ events (tracks) in energy group g during history h. r_{e-1} and r_e are the beginning and end coordinates of the track segment tallied, and w_e is the particle weight. The integral over the track is its length, ℓ . Replacing the sums with the more compact expected value notation, "< >", we have

$$\phi_g \approx V \langle\phi\rangle \tag{3}$$

Similarly, a region's group reaction rate is defined by

$$R_g = \int_V \int_{\Delta E_g} n(r)\,\sigma(r,E)\,\phi(r,E)\,dV\,dE \tag{4}$$

where σ is the microscopic cross section for the reaction rate of interest, and n(r) is the isotopic atom density. VIM estimates this quantity according to

$$R_g \approx \frac{1}{N_B} \sum_{b=1}^{N_B} \frac{1}{N_H} \sum_{L=1}^{N_H} \sum_{e\in(h,g)}^{N_e(h,g)} w_e \int_{r_{e-1}}^{r_e} n(r)\,\sigma(r,E_e)\,dr \tag{5}$$

If the edit group structure corresponds to the multigroup set's, then $\sigma(r,E)$ becomes $\sigma_g(r)$. Furthermore, if each edit region contains only one composition, the n(r) and $\sigma_g(r)$ are constant along the track segment.

We estimate the microscopic cross section by taking the per atom ratio of the above tallies:

$$\langle\sigma_g\rangle \approx \frac{R_g}{n\phi_g} \tag{6}$$

or, since, for the special conditions described above, $n(\mathbf{r})\sigma(\mathbf{r},E) = n\sigma_g$,

$$\langle\sigma_g\rangle \approx \frac{n\,\sigma_g\,V\,\langle\phi\rangle}{n\,V\,\langle\phi\rangle} \tag{7}$$

which is the exact value of the cross section. In VIM, the variance in $\langle\sigma_g\rangle$ is computed correcting for the correlation between the group flux and the group reaction rate. This correction removes the contribution of the flux variance to the reaction rate variance, leaving only the cross section variance within the edit group. Even for continuous-energy cross sections which vary dramatically within a group, the correlation can be very important. Specifically, we compute the cross section variance as

$$\frac{\text{var}\,(\langle\sigma_g\rangle)}{\langle\sigma_g\rangle^2} = \frac{\text{var}\,(\langle n\,\sigma_g V\phi\rangle)}{(\langle n\sigma_g V\phi\rangle)^2} + \frac{\text{var}\,(\langle nV\phi\rangle)}{(\langle nV\phi\rangle)^2} - 2\,\frac{\text{cov}\,(\langle n\sigma_g V\phi\rangle, \langle nv\phi\rangle)}{\langle n\sigma_g V\phi\rangle\,\langle nV\phi\rangle} \tag{8}$$

With the edit region and group structure restrictions described above, all variables except ϕ are constant. Since

$$\text{var}\,(\langle\phi\rangle) = \langle\phi^2\rangle - \langle\phi\rangle^2 \tag{9}$$

and

$$\text{cov}\,(\langle\phi\rangle, \langle\phi\rangle) = \langle\phi^2\rangle - \langle\phi\rangle^2 \tag{10}$$

the cross section variance is zero if there are any tallies at all in the region and group. The zero variance provides a fast high-precision check of the multigroup VIM principal cross sections. This is not the case for the group-to-group scattering cross section estimates, because $\sigma_{gg'}$ at a point in an incident

group is represented by a probability distribution rather than a constant. Then, $\sigma_{gg'}(r,E)$ remains in the integrand of Eq. (5), the estimate of $\langle\sigma_{gg'}\rangle$ is not perfectly correlated with the flux, and the variance is non-zero.

IV. Benchmark Results

In test problem 1, P1, two-group cross sections (Table 1), were devised to maximize the scattering anisotropy, but constrained to keep the scattering angle cosine probability density non-negative. The problem, shown in Fig. 2, is a one-dimensional cell surrounded by a specular reflector. Each atom density is 1.0. In Table 2, the VIM results are compared with those from a TWODANT S_{16} calculation using the same ISOTXS file and $\Delta x = 0.31496$ cm, which was found to converge the fission source spatial distribution. The isotropic scattering case is included to demonstrate the importance of anisotropy here. Both cases show good agreement between codes.

In the test problem 2, the VIM material files were produced by converting an 9-group ISOTXS file including P1 in-group scattering and P1 down-scattering. Some of the P1 scattering cross sections were reduced to eliminate negative angular probability densities. The problem derives from a highly simplified 2D EBR layout (see Fig. 3) with two material zones (core surrounded by stainless steel radial reflector), and invokes the hexagonal lattice geometry option. Eight million histories were run, and the resulting high-precision eigenvalue estimates (Table 3) compare well with two other transport solutions (Ref. 11). In addition, each group-to-group cross section (P0 and P1 scattering, and N2N), and the average in-group scattering angle cosine were compared to the ISOTXS values. These comparisons, shown in Tables 4-11 show good detailed agreement. The principal cross sections (not shown here) agreed perfectly.

Two additional tests of ISOVIM were completed. Test problem 3 was a 9-group P0 ISOTXS file containing ENDF/B-V ^{239}Pu; every cross section in this file agreed with the corresponding cross section in the VIM output. Test problem 4

was a 10-group HTGR ISOTXS file which contained upscatter. For several of the nuclides, including one with upscatter, every cross section was compared to and agreed with the VIM result; spot checks were made for several other nuclides.

The data defining test problems 1 through 4 can be found in datasets named in Table 12.

Reference 12 describes a benchmark calculation performed with VIM material files produced "by hand." References 13 and 14 document benchmark calculations with data input to ISOVIM in CASMO output format.

Reference 15 describes a comparison of a two group VIM calculation with P_3 scattering with several deterministic methods. In this case, the only discrepancies were disagreement of the P_2 and P_3 scattering cross sections with the original ISOTXS values, and non-zero P_4 scattering cross sections. By replacing the standard uniform 20-interval angular distribution with a uniform 100-interval table, the differences and the non-zero P_4 cross section were determined to be due to the coarseness of the angular mesh (see table 13).

In summary, nine multigroup VIM calculations have been run which serve as verification tests for ISOVIM and the handful of VIM code modifications necessary to perform multigroup calculations. These used several methods of cross section input: hand-crafted ascii material files, conversion of ISOTXS files, and conversion of CASMO output edits. The problems spanned a range of nuclear data characteristics, including isotropic and anisotropic within-group and group-to-group scattering, upscatter, and fission. The benchmark solutions were generated by a variety of transport methods, including discrete ordinates, variational nodal transport, and integral transport. All of the results show that ISOVIM correctly generates the multigroups VIM material files and that VIM correctly solves the multigroup physics problem.

V. CONCLUSIONS

The procedures for generating multigroup VIM material files have been described, based on four data sources: ISOTXS files, COMPXS files, CASMO edits, and hand-crafted VIM material files. The application of piecewise linear distributions to specify piecewise constant behavior was reviewed and the relevant details for multigroup VIM material files have been laid out. The variance behavior of the VIM cross section estimates was analyzed to show how multigroup VIM material files can be checked for errors, and as a backdrop for the benchmark comparisons. Four benchmark calculations (plus an isotropic variant of problem 1) were described, and the results presented. Finally, several additional high precision transport comparisons described elsewhere have been referenced.

ISOVIM is now maintained under the same configuration control regime which is applied to VIM, and is available for use.

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APPENDIX A
VIM Multigroup Material File Details

Note - since some of the card-image formats use the 1P multiplier, floating point numbers must be input with exponents. See the VIM User's Guide (Ref 4, Appendix F) for the detailed file description.

Record Type	Requirements
Header	1 card VIM material ID # < 209999 for fissionable isotopes, > 210000 for non-fissionable isotopes
1	>= 6 cards all integers = 0, except: LFI (=1 if fissionable), NLEV (= # of levels needed for anisotropic outscatter) NPTS = NGROUP*2 + 1 IN2N (=1 if n,2n is to be included) LNU (=2 if fissionable) NR (=1) IRANGE (=2) KRI (<= top of energy group below all inelastic) KRF (<= NPTS, if fissionable) floating-point data zero except: AWR = 1.0+10 ASQP1 = 1.0+20 ALPCON = 1.0+20 ALEF = 1.0 TWOA = 2.0+10 ERANGE <= ECUT (VIM input) ETHIN (usually EGRID(KRI); top of highest energy group with no outscatter.) TLAB = 300.
2	>= 1 card for elastic almost double-point group boundaries
3	>= 1 card
4	>= 1 card
5	>= 1 card if fissionable
6	>= 1 card if fissionable
10	>= 1 card
11	identical to 10
12	1 card for elastic ESTART = ETOP (VIM input) for lab-isotropic scattering = lowest energy for anisotropic in-group scattering NANG = 0 for lab-isotropic scattering NANG = # of energy grid points for which in-group scattering is anisotropic. Use near double-pointing here. LEV = 0 INT = 1
13	one set of record 13 cards for each NANG points (ordered by deceasing EANG)

APPENDIX A (Cont'd)

```
12      1 card for n, 2n
          Estart = ETOP
          NANG = 0
          LEV = - 34
          Repeat 12 and 13 NLEV times:
12      1 card for each level
          ESTART = bottom of incident energy group
          NANG = 3
          LEV = level #
          INT = 1
13      3 sets:
          (1) EANG = top of incident group
          (2) EANG = bottom of incident group
          (3) If anisotropic out scatter is present:
              EANG = bottom of incident group, ANGDIS (1) = secondary group
                                                            upper energy
                                               ANGDIS (2) = secondary group
                                                            lower energy
14      1 card for fission
          NK=1
15      2 cards for fission
          NK1 = 1
          LF = 1
          NP = 2
          INT1 = 2
          NE = # of incident energies (<= NPTS or KRF)
          INT2 = 2
          U = 0.0
          EP(1) = EGRID(1), EP(2) = EGRID(NPTS)
          P(1) = 0.0, P(2) = 1.0
16B     NE sets for fission
          INT3 = 2
14      1 card if n,2n
15      2 cards if n,2n
          same as for fission, except:
          NE = # of incident energies (<= NPTS or KRI)
16B     NE sets if n,2n
14      1 card for inelastic continuum (all out-of-group) scattering
15      2 cards for inelastic continuum
          same as for fission, except:
          NE = # of incident energies (<= NPTS or KRI)
16B     NE sets for inelastic continuum
21, 22  26 standard dummy photon data cards:
1.0           2.0                                                    0.0
              148.0
100000000.    1000.       1.0         1.0         1.0         1.0
1.0           1.0         1.0         1.0         0.0         0.0
0.0           0.0         0.0         0.0         0.0         0.0
0.0           0.0         0.0         0.0         0.0         0.0
0.0           0.0         0.0         0.0         0.0         0.0
0.0           0.0         0.0         0.0         0.0         0.0
```

APPENDIX A (Cont'd)

```
0.0         0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         1.0         1.0
```

```
//////////END OF DATA///000001///FUEL1 ////////////////////
```

APPENDIX B
Sample Multigroup Material Files

```
000001      FUEL1
000001     4     0     1     0     2     0     0     0     0     0     0
    0     1.  E+10     1.  E+20     1.  E+20          1.0     2.  E+10     1
 1.0     E-05
     2
     3     4 1.0     E+00     0
   3.0   E+02           0.           0.  0    0.
 2.000000E+07 1.00001 E+00 1.00000 E+00 1.000000E-05
 2.531   E-01 2.531   E-01 5.732   E-01 5.732   E-01
 2.33427 E-01 2.33427 E-01 5.1428  E-01 5.1428  E-01
 2.281   E-03 2.281   E-03 4.038   E-02 4.038   E-02
    4 2.000000E+07 1.00001 E+00 1.000000E+00 1.000000E-05 2.59755 E+00
2.59755  E+002.43115  E+002.43115  E+00
 1.069   E-02 1.069   E-02 0.0
 1.069   E-02 1.069   E-02 0.0
 2.0     E+07     0     0     2
     1     0     0     0     0     0     0     0     0     0     0
     1     1     2     2     2     2          0.0 2.0     E+07 0.0
 1.0     E-05 1.0     E+00
 2.0     E+07     2     2 1.00001 E+06 0.0     E+00 1.000000E+06 1.0     E+00

 1.0     E-05     2     2 1.00001 E+06 0.0     E+00 1.000000E+06 1.0     E+00

     1     0     0     0     0     0     0     0     0     0     0
     1     1     2     2     2     2          0.0 2.0     E+07 0.0
 1.0     E-05 1.0     E+00
 2.0     E+07     2     2 0.50001 E+00 0.0     E+00 0.500000E+00 1.0     E+00

 1.0     E+00     2     2 0.50001 E+00 0.0     E+00 0.500000E+00 1.0     E+00

1.0          2.0                                                    0.0
             148.0
100000000.   1000.        1.0          1.0          1.0          1.0
1.0          1.0          1.0          1.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0          0.0
0.0          0.0          0.0          0.0          0.0          0.0
```

APPENDIX B (Cont'd)

```
0.0         0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         1.0         1.0

//////////END OF DATA///000001///FUEL1 /////////////////////

210001     CAN
210001     4     0     0     0     0     0     0     0     0     0     0
     0     1.  E+10     1.  E+20     1.  E+20         1.0       2.  E+10     1
 1.0      E-05
     2
     3     0 1.0      E+00      0
  3.0     E+02              0.            0.  0     0.
 2.000000E+07 1.000001E+00 1.000000E+00 1.000000E-05
 2.172    E-01 2.172    E-01 4.748    E-01 4.748    E-01
 2.07062  E-01 2.07062  E-01 4.70406  E-01 4.70406  E-01
 9.095    E-03 9.095    E-03 0.0
 9.095    E-03 9.095    E-03 0.0
 2.0      E+07     0     0     2
     1     0     0     0     0     0     0     0     0     0     0
     1     1     2     2     2     2           0.0 2.0      E+07 0.0
 1.0      E-05 1.0      E+00
 2.0      E+07     2     2 0.500001E+00 0.0      E+00 0.500000E+00 1.0      E+00

 1.0      E+00     2     2 0.500001E+00 0.0      E+00 0.500000E+00 1.0      E+00

1.0         2.0                                                  0.0
            148.0
100000000.  1000.       1.0         1.0         1.0         1.0
1.0         1.0         1.0         1.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0         0.0
0.0         0.0         0.0         0.0         0.0         0.0
```

APPENDIX B (Cont'd)

```
0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     0.0     0.0     0.0
0.0     0.0     0.0     1.0     1.0
```

```
//////////END OF DATA///210001///CAN   ////////////////////
```

APPENDIX C
ISOVIM Input Description

```
C*********************************************************************
CF                                                                    -
CE        GENERAL INPUT FOR ISOVIM Version 3.4  (September 1992)      -
C                                                                     -
CN          USER SUPPLIES THIS DATASET TO STANDARD INPUT.             -
C                                                                     -
C       Processing of card image cross section data by J. Vujic.      -
C                                                                     -
C*********************************************************************
C---------------------------------------------------------------------
CR          CONTROL FLAGS                              (TYPE 01)      -
C                                                                     -
CC    ALWAYS PRESENT                                                  -
C                                                                     -
CL    FORMAT-----(4I6)                                                -
C                                                                     -
CD    COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                -
CD    =======   ========================================================
CD    1-6       KFILE   FILE ID FLAG                                  -
CD              0...PROCESS A COMPXS FILE  (DEFAULT)                  -
CD              1...PROCESS AN ISOTXS FILE                            -
CD              2...PROCESS A CARD IMAGE CROSS SECTION FILE (CICS)     -
CD                                                                    -
CD    7-12      ICOR    TRANSPORT CORRECTION FLAG                     -
CD              0...DO NOT TRANSPORT CORRECT   (DEFAULT)              -
CD              1...TRANSPORT CORRECT                                 -
CD                                                                    -
CD    13-18     ISCT    LEGENDRE ORDER OF P-N SCATTERING TO BE        -
CD                  INCORPORATED INTO TABULATED ANGULAR DISTRIBUTIONS. -
CD                  APPLIES ONLY TO IN-GROUP SCATTERING.  CAN BE USED -
CD                  TO TRUNCATE HIGHER-ORDER IN EXPANSIONS            -
CD              0...ISOTROPIC  (DEFAULT)                              -
CD              N...P-N ORDER                                         -
CD                                                                    -
CD    19-24     IDBG    DEBUG PRINT FLAG                              -
CD              0.....NO DEBUG PRINTS  (DEFAULT)                      -
CD              ISO...TURNS ON DEBUG PRINTS FOR ISOTOPE # ISO         -
CD                                                                    -
CN              COMPXS WILL BE PROCESSED AS PO SCATTERING.            -
C                                                                     -
C---------------------------------------------------------------------
C---------------------------------------------------------------------
CR          CICS: BASIC DATA                           (TYPE 02)      -
C                                                                     -
CC          PRESENT IF KFILE.EQ.2                                     -
C                                                                     -
CL    FORMAT-----(2I6)                                                -
C                                                                     -
CD    COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                -
CD    =======   ========================================================
```

APPENDIX C (Cont'd)

```
CD    1-6       NCMP    TOTAL NUMBER OF COMPOSITIONS                    -
CD    7-12      NGROUP  TOTAL NUMBER OF ENERGY GROUPS                   -
CD                                                                      -
C                                                                       -
CN              EXISTS ONLY WHEN PROCESSING CARD IMAGE CROSS SECTION    -
CN              FILES (CICS)                                            -
C                                                                       -
C-----------------------------------------------------------------------
C-----------------------------------------------------------------------
CR          CICS: UPPER ENERGY BOUNDARIES            (TYPE 03)          -
C                                                                       -
CC          PRESENT IF KFILE.EQ.2                                       -
C                                                                       -
CL    (EMAX(I),I=1,NGROUP)                                              -
C                                                                       -
CL    FORMAT-----(10E13.5)                                              -
C                                                                       -
CD    EMAX(I)             UPPER ENERGY BOUNDARIES (EV), HIGH TO LOW.    -
CD                                                                      -
C                                                                       -
CN              EXISTS ONLY WHEN PROCESSING CARD IMAGE CROSS SECTION    -
CN              FILES (CICS)                                            -
C                                                                       -
C-----------------------------------------------------------------------
C-----------------------------------------------------------------------
CR          LABELS AND VIM ID NUMBERS                (TYPE 04)          -
C                                                                       -
CC    ALWAYS PRESENT                                                    -
C                                                                       -
CL    FORMAT-----(A6,6X,I6)                                             -
C                                                                       -
CD    COLUMNS             CONTENTS...IMPLICATIONS, IF ANY               -
CD    =======   ===========================================================
CD    1-12      HISONM    ISOTOPE OR COMPOSITION LABEL                  -
CD                                                                      -
CD    13-24     MATID     VIM MATERIAL FILE NUMBER TO BE USED           -
CD                                                                      -
C                                                                       -
CN              NISO TYPE 04 CARDS MUST BE USED TO CONVERT ALL OF THE   -
CN              ISOTXS FILE DATA TO VIM MATERIAL FILES.                 -
CN                                                                      -
CN              NCMP TYPE 04 CARDS MUST BE USED TO CONVERT ALL OF THE   -
CN              CASMO/CPM-2 FILE DATA TO VIM MATERIAL FILES.            -
C                                                                       -
C-----------------------------------------------------------------------
C-----------------------------------------------------------------------
CR          CICS: FRACTION OF FISSION NEUTRONS         (TYPE 05)        -
C                                                                       -
CC          PRESENT IF KFILE.EQ.2                                       -
```

APPENDIX C (Cont'd)

```
C                                                                       -
CL    (CHI(I),I=1,NGROUP)                                               -
C                                                                       -
CL    FORMAT-----(10E13.5)                                              -
C                                                                       -
CD    CHI(I)           FRACTION OF FISSION NEUTRONS IN GROUP I          -
CD                                                                      -
C                                                                       -
CN             EXISTS ONLY WHEN PROCESSING CARD IMAGE CROSS SECTION     -
CN             FILES (CICS)                                             -
C                                                                       -
C-----------------------------------------------------------------------
C-----------------------------------------------------------------------
CR          CICS: FISSION FLAG                          (TYPE 06)       -
C                                                                       -
CC          PRESENT IF KFILE.EQ. 2                                      -
C                                                                       -
CL    FORMAT-----(I6)                                                   -
C                                                                       -
CD    COLUMNS          CONTENTS...IMPLICATIONS, IF ANY                  -
CD    =======   ========================================================
CD    1-6       IFIS     FISSION FLAG.                                  -
CD              0...NOT FISSIONABLE.                                    -
CD              1...FISSIONABLE.                                        -
CD                                                                      -
C                                                                       -
CN             EXISTS ONLY WHEN PROCESSING CARD IMAGE CROSS SECTION     -
CN             FILES (CICS)                                             -
C                                                                       -
C-----------------------------------------------------------------------
C-----------------------------------------------------------------------
CR          CICS: ABSORPTION CROSS SECTION              (TYPE 07)       -
C                                                                       -
CC          PRESENT IF KFILE.EQ.2                                       -
C                                                                       -
CL    (SABS(I),I=1,NGROUP)                                              -
C                                                                       -
CL    FORMAT-----(10E13.5)                                              -
C                                                                       -
CD    SABS(I)        MACROSCOPIC ABSORPTION CROSS SECTION IN GROUP I    -
CD                                                                      -
C                                                                       -
CN             EXISTS ONLY WHEN PROCESSING CARD IMAGE CROSS SECTION     -
CN             FILES (CICS)                                             -
C                                                                       -
C-----------------------------------------------------------------------
C-----------------------------------------------------------------------
CR          CICS: FISSION CROSS SECTION                 (TYPE 08)       -
C                                                                       -
CC          PRESENT IF KFILE.EQ.2                                       -
C                                                                       -
CL    (SFIS(I),I=1,NGROUP)                                              -
```

APPENDIX C (Cont'd)

```
CL    FORMAT-----(10E13.5)                                                  -
C                                                                           -
CD    SFIS(I)        MACROSCOPIC FISSION CROSS SECTION IN GROUP I           -
CD                                                                          -
C                                                                           -
CN             EXISTS ONLY WHEN PROCESSING CARD IMAGE CROSS SECTION         -
CN             FILES (CICS)                                                 -
C                                                                           -
C---------------------------------------------------------------------------
C---------------------------------------------------------------------------
CR          CICS: NUFISSION CROSS SECTION                (TYPE 09)          -
C                                                                           -
CC          PRESENT IF KFILE.EQ.2                                           -
C                                                                           -
CL    (SNUFIS(I),I=1,NGROUP)                                                -
C                                                                           -
CL    FORMAT-----(10E13.5)                                                  -
C                                                                           -
CD    SNUFIS(I)      MACROSCOPIC NU FISSION CROSS SECTION IN GROUP I        -
CD                                                                          -
C                                                                           -
CN             EXISTS ONLY WHEN PROCESSING CARD IMAGE CROSS SECTION         -
CN             FILES (CICS)                                                 -
C                                                                           -
C---------------------------------------------------------------------------
C---------------------------------------------------------------------------
CR          CICS: TRANSPORT CROSS SECTION                (TYPE 10)          -
C                                                                           -
CC          PRESENT IF KFILE.EQ.2                                           -
C                                                                           -
CL    (STOTPL(I),I=1,NGROUP)                                                -
C                                                                           -
CL    FORMAT-----(10E13.5)                                                  -
C                                                                           -
CD    STOTPL(I)      MACROSCOPIC TOTAL CROSS SECTION IN GROUP I             -
CD                   TRANSPORT CORRECTED                                    -
CD                                                                          -
C                                                                           -
CN             EXISTS ONLY WHEN PROCESSING CARD IMAGE CROSS SECTION         -
CN             FILES (CICS)                                                 -
C                                                                           -
C---------------------------------------------------------------------------
C---------------------------------------------------------------------------
CR          CICS: TOTAL SCATTERING CROSS SECTION         (TYPE 11)          -
C                                                                           -
CC          PRESENT IF KFILE.EQ.2                                           -
C                                                                           -
CL    (STOTSC(I),I=1,NGROUP)                                                -
C                                                                           -
CL    FORMAT-----(10E13.5)                                                  -
```

APPENDIX C (Cont'd)

```
C                                                                       -
CD    STOTSC(I)     MACROSCOPIC TOTAL SCATTERING CROSS SECTION IN       -
CD                  GROUP I,  TRANSPORT CORRECTED                       -
CD                                                                      -
C                                                                       -
CN             EXISTS ONLY WHEN PROCESSING CARD IMAGE CROSS SECTION     -
CN             FILES (CICS)                                             -
C                                                                       -
C-----------------------------------------------------------------------
C-----------------------------------------------------------------------
CR          CICS: P0 SCATTERING MATRIX                    (TYPE 12)     -
C                                                                       -
CC          PRESENT IF KFILE.EQ.2                                       -
C                                                                       -
CL    (XSP0(J,I),I=1,NGROUP),J=1,NGROUP)                                -
C                                                                       -
CL    FORMAT-----(10E13.5)                                              -
C                                                                       -
CD    XSP0(J,I)     MACROSCOPIC SCATTERING CROSS SECTION FROM GROUP     -
CD                  J TO GROUP I.                                       -
CD                  DIAGONAL ELEMENTS ARE TRANSPORT CORRECTED.          -
CD                                                                      -
C                                                                       -
CN             EXISTS ONLY WHEN PROCESSING CARD IMAGE CROSS SECTION     -
CN             FILES (CICS)                                             -
C                                                                       -
CN             REPEAT CARDS 06 TO 12 NCMS TIMES.                        -
C                                                                       -
C-----------------------------------------------------------------------
```

This dataset is in ~b24366/isovim/isovim.in.manual on the ANL RA Division Unix Network

APPENDIX D
ISOVIM Sample Input

```
    2      0      0
    5      6
  1.00000E+07  8.21000E+05  4.00000E+00  6.25000E-01  2.20000E-01  5.80000E-02
FUEL          000001
GRAP1         210001
GRAPT         210002
COOLAN        210003
TARGET        210004
  0.75601E+00  0.24400E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
     1
  3.86028E-04  5.06650E-03  1.08669E-02  3.81127E-02  6.59634E-02  1.37752E-01
  2.94218E-04  3.05299E-03  8.58140E-03  3.16057E-02  5.53762E-02  1.17378E-01
  7.87044E-04  7.38810E-03  2.07566E-02  7.64474E-02  1.33945E-01  2.83911E-01
  1.36499E-01  3.02322E-01  3.30463E-01  3.22578E-01  3.21671E-01  5.01619E-01
  1.36113E-01  2.97256E-01  3.19596E-01  2.84466E-01  2.55707E-01  3.63867E-01
  1.16672E-01  1.94414E-02  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  2.93980E-01  3.27562E-03  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  1.43510E-06  2.94670E-01  2.48125E-02  9.03093E-05  2.19450E-05
  0.00000E+00  0.00000E+00  1.46620E-03  2.48331E-01  3.38298E-02  8.38642E-04
  0.00000E+00  0.00000E+00  2.09694E-10  3.57128E-03  2.41652E-01  1.04842E-02
  0.00000E+00  0.00000E+00  0.00000E+00  1.06264E-05  1.14072E-02  3.52449E-01
     0
  5.97016E-05  5.99098E-06  7.10639E-05  1.43164E-04  2.54349E-04  4.77556E-04
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  1.63701E-01  3.66199E-01  3.94830E-01  3.49294E-01  3.12338E-01  4.51913E-01
  1.63642E-01  3.66193E-01  3.94759E-01  3.49151E-01  3.12084E-01  4.51435E-01
  1.40036E-01  2.36057E-02  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  3.62027E-01  4.16619E-03  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  3.63275E-01  3.13395E-02  1.16092E-04  2.82101E-05
  0.00000E+00  0.00000E+00  1.76916E-03  3.03923E-01  4.23787E-02  1.08031E-03
  0.00000E+00  0.00000E+00  2.68082E-10  4.26897E-03  2.95181E-01  1.26344E-02
  0.00000E+00  0.00000E+00  0.00000E+00  1.35614E-05  1.27545E-02  4.38667E-01
     0
  5.37046E-05  5.58814E-06  6.61232E-05  1.33332E-04  2.36426E-04  4.43587E-04
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  1.52655E-01  3.40994E-01  3.67606E-01  3.25179E-01  2.90629E-01  4.20484E-01
  1.52601E-01  3.40988E-01  3.67540E-01  3.25045E-01  2.90392E-01  4.20040E-01
  1.30466E-01  2.21359E-02  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  3.37104E-01  3.88389E-03  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  3.38322E-01  2.90846E-02  1.07704E-04  2.61707E-05
  0.00000E+00  0.00000E+00  1.64388E-03  2.82881E-01  3.95128E-02  1.00722E-03
  0.00000E+00  0.00000E+00  2.52598E-10  4.02316E-03  2.74659E-01  1.17097E-02
  0.00000E+00  0.00000E+00  0.00000E+00  1.26642E-05  1.19092E-02  4.08118E-01
     0
  1.34235E-08  1.34241E-08  1.34554E-08  1.35472E-08  1.38207E-08  1.49326E-08
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
  3.99153E-03  1.25884E-03  8.68137E-04  8.60295E-04  9.02717E-04  9.67039E-04
  3.99152E-03  1.25882E-03  8.68123E-04  8.60281E-04  9.02703E-04  9.67024E-04
```

APPENDIX D (Cont'd)

1.64324E-03	2.34827E-03	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
0.00000E+00	1.23114E-03	2.76847E-05	0.00000E+00	0.00000E+00	0.00000E+00
0.00000E+00	0.00000E+00	6.40887E-04	2.21395E-04	5.83590E-06	5.20323E-09
0.00000E+00	0.00000E+00	2.93295E-06	4.92265E-04	3.56323E-04	8.76072E-06
0.00000E+00	0.00000E+00	-1.38125E-10	2.05609E-05	6.56851E-04	2.25291E-04
0.00000E+00	0.00000E+00	-9.93151E-12	8.95623E-09	2.35430E-04	7.31585E-04
0					
9.67304E-05	1.55023E-03	1.79638E-02	3.60661E-02	6.41233E-02	1.20869E-01
0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
1.19648E-01	2.54955E-01	2.72890E-01	2.91286E-01	3.10820E-01	3.70885E-01
1.19552E-01	2.53405E-01	2.54926E-01	2.55220E-01	2.46697E-01	2.50016E-01
9.59704E-02	2.35812E-02	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
0.00000E+00	2.50453E-01	2.95193E-03	0.00000E+00	0.00000E+00	0.00000E+00
0.00000E+00	6.29901E-05	2.31620E-01	2.31360E-02	1.05672E-04	1.75742E-06
0.00000E+00	0.00000E+00	2.96692E-03	2.14258E-01	3.72617E-02	7.33078E-04
0.00000E+00	0.00000E+00	-1.46614E-11	9.23574E-03	2.21766E-01	1.56957E-02
0.00000E+00	0.00000E+00	-5.13182E-13	1.76896E-04	3.36548E-02	2.16185E-01

APPENDIX E

(1) XSEDIT Sample Input (File XSFTO5) to convert card-image file to binary.

```
   1    2    1    0    1
210001
```

(2) FILEONE Sample Input (File F1FT05):

```
   1
000001FUEL1    22    0
000002FUEL2    23    0
000003FUEL3    24    0
000004FUEL4    25    0
000005BPOIS    26    0
210001CAN      27    0
210002H2O      28    0
210003BLADE    29    0
```

(Isotopes should appear in the input in ascending order of VIM ID numbers.)

(3) BANDIT Sample Input (File BAND05)

```
   8    3         1   01  5000     0 300.0     0
   1    2    3    4    5210001210002210003
 2.0   E+07  1.0001E-05 1.000  E-05
```

Notes:
NLAYER must be set to 3.
MAXIT must be set to 1
LTHERM must be set to 0.
Card type 4 must be used (vice card type 3), where the first (ETOP) and last (ECUT) entries are the top and bottom of the multigroup energy range, and the second-to-last entry must be between the inelastic threshold and ECUT. This ensures that no inelastic data is included in the lower energy band.

These bands are unrelated to the energy groups

APPENDIX F

get.binary Script

```
#! /bin/sh
#
# Script to take XSFT08, produced by ISOVIM, and convert it to
# binary VIM material files with the standard naming convention.
# The script gets its list of materials to find in XSFT08 from
# the standard FILEONE input file, F1FT05, also produced by ISOVIM.
#
# F1FT05 goes through 3 steps:
#   1.  "cut" out all text after column 6, leaving only the VIM
#       material ID numbers.
#   2.  Delete the 1st line from the result of step 1.
#   3.  Insert leading zeroes when the VIM material id numbers
#       are less than 100000.
#
cut -c1-6 ISOVIM.F1FT05 |
sed -e "1d" |
sed -e "s/^     /00000/"  |
sed -e "s/^    /0000/"  |
sed -e "s/^   /000/"  |
sed -e "s/^  /00/"  |
sed -e "s/^ /0/"  |
# loop over all the VIM id #'s in F1FT05(processed)
while read MAT
do
cat > XSFT05 < < EOF
    1    2    1    0    1    0    0    0 50000    0    2    0
$MAT
EOF
```

Figure 1. Flowchart for Generating a Multigroup VIM Library

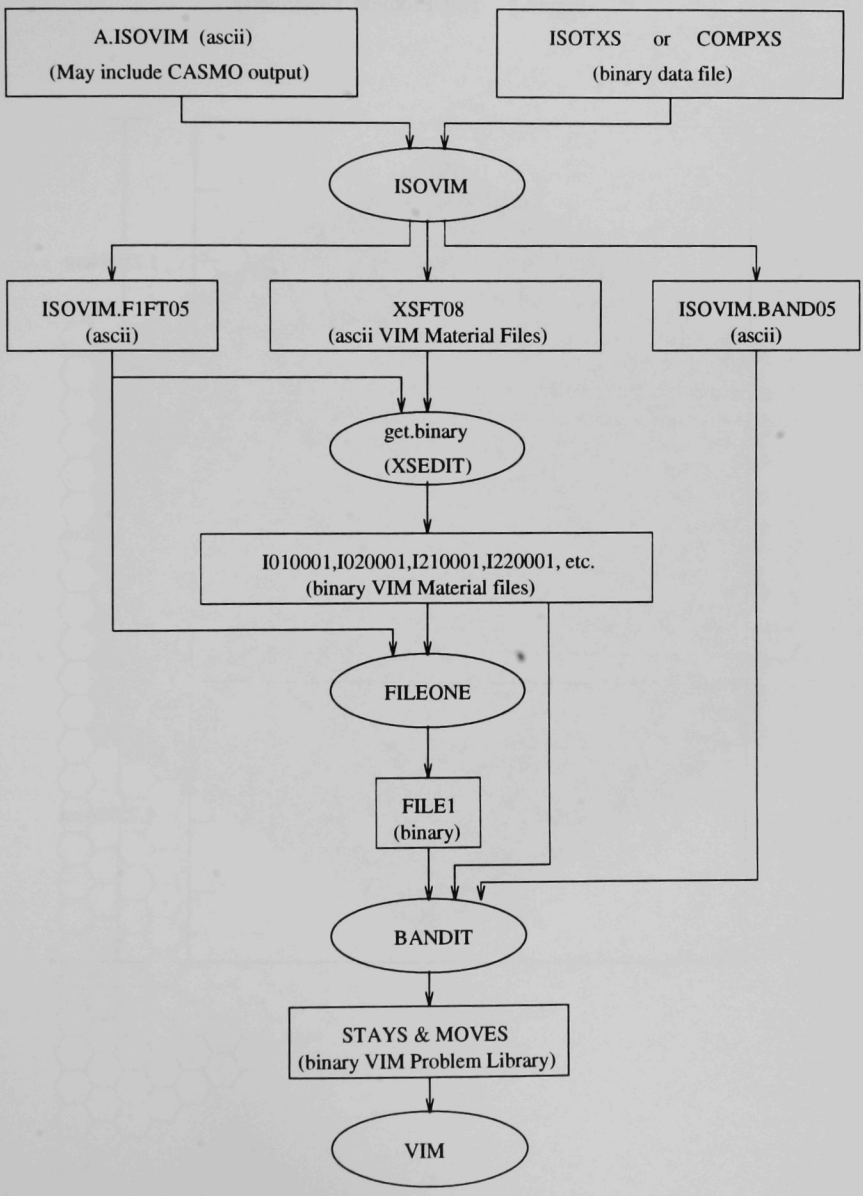

Figure 2. Test Problem 1 Geometry

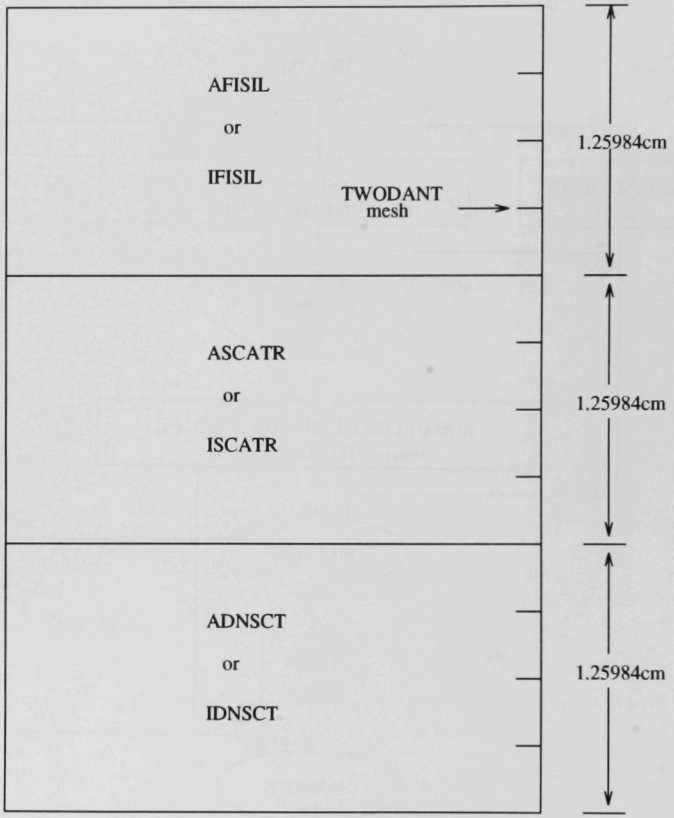

Figure 3. Test Problem 2 Geometry

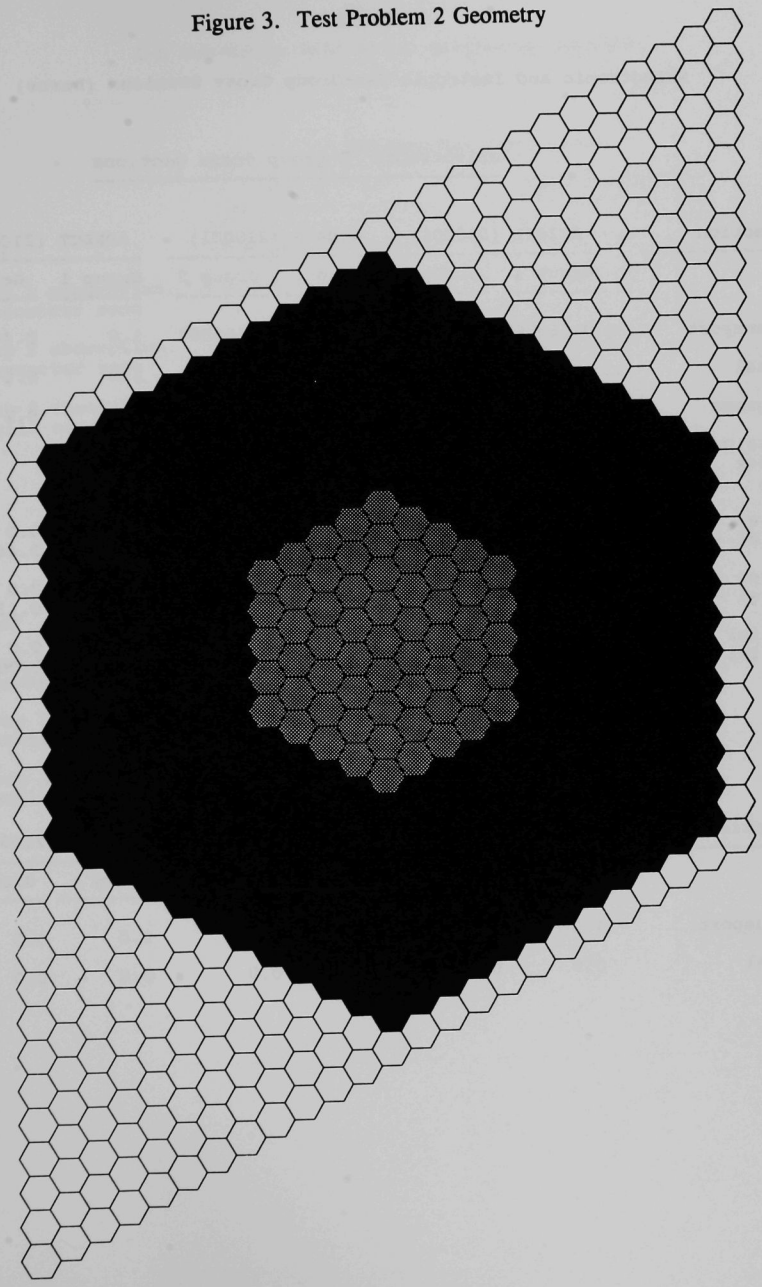

Table 1

Anisotropic and Isotropic Two-Group Cross Sections (barns)

anisotropic 2-group cross sections

Reaction	AFISIL (000001)		ASCATR (210001)		ADNSCT (210002)	
	Group 1	Group 2	Group 1	Group 2	Group 1	Group 2
Transport	0.666667	0.966667	0.666667	0.666667	1.0	0.466667
Total	1.0	1.0	1.0	1.0	1.0	0.6
n,gamma	0.0	0.0	0.0	0.0	0.2	0.2
fission	0.0	0.9				
nubar	2.5	2.5				
chi	1.0	0.0				
P0 el --> G1	1.0	0.00	1.00	0.00	0.35	0.0
P0 el --> G2	0.00	0.1	0.00	1.00	0.40	0.40
P1 el --> G1	0.333333	0.0	0.333333	0.0	0.0	0.0
P1 el --> G2	0.0	0.033333	0.0	0.333333	0.0	0.133333
P0 inl --> G1	0.00	0.00	0.00	0.00	0.00	0.0
P0 inl --> G2	0.00	0.00	0.00	0.00	0.05	0.00

isotropic 2-group cross sections

Reaction	IFISIL (000002)		ISCATR (210003)		IDNSCT (210004)	
	Group 1	Group 2	Group 1	Group 2	Group 1	Group 2
Transport	1.0	1.0	1.0	1.0	1.0	0.6
P1 el	0.0	0.0	0.0	0.0	0.0	0.0

Table 2

1-D Two-Group Scattering Anisotropy Results

Anisotropic Scattering

	VIM +/- 1σ	TWODANT/VIM-1(%)
k-inf	0.69346 +/- 0.11%	-0.010
Group 1 absorption, downscatter zone	0.30766 +/- 0.10%	0.009
Group 2 absorption, downscatter zone	0.41501 +/- 0.08%	-0.015
Group 2 absorption, fissile zone	0.27733 +/- 0.15%	0.009

Isotropic Scattering

	VIM +/- 1σ	TWODANT/VIM-1(%)
k-inf	0.61128 +/- 0.12%	-0.117
Group 1 absorption, downscatter zone	0.30779 +/- 0.10%	0.032
Group 2 absorption, downscatter zone	0.44769 +/- 0.18%	0.087
Group 2 absorption, fissile zone	0.24452 +/- 0.14%	-0.123

Table 3

EBR Nine-Group K-eff Results

TWOHEX (Ref. 16) (S8, 24 triangles per hex)	1.30925
DIF3D Nodal Transport (Ref. 17) (4th order spatial, P3 angular)	1.30985

VIM Estimate*	ANALOG	TRACK LENGTH	COLLISION
K-eff	1.31050	1.30985	1.30984
Est. Stnd. Dev.	0.00047	0.00066	0.00065
VIM - Nodal Transport	0.00065	0.0	0.00001

* from two independent VIM simulations

Table 4

EBR Average In-Group Scattering/N2N Angle Cosine (COR1)

Group	VIM MUBAR	Absolute Error	ISOTXS MUBAR	(VIM-ISOTXS) /Sigma*
1	3.1684E-01	2.24E-03	3.1922E-01	-1.06
2	2.8804E-01	3.57E-04	2.8862E-01	-0.16
3	2.9132E-01	1.65E-04	2.9238E-01	-6.40
4	1.6455E-01	2.21E-04	1.6517E-01	-2.83
5	8.3070E-02	2.28E-04	8.3319E-02	-1.09
6	4.7861E-02	3.60E-04	4.7843E-02	0.05
7	2.3742E-02	4.65E-04	2.4343E-02	-1.29
8	2.3834E-02	9.70E-04	2.4592E-02	-0.78
9	1.9823E-02	8.04E-04	1.8813E-02	1.26

* One standard deviation of the mean

Table 5

EBR Average In-Group Scattering/N2N Angle Cosine (SSTRR)

Group	VIM MUBAR	Absolute Error	ISOTXS MUBAR	(VIM-ISOTXS) /Sigma*
1	3.2907E-01	3.60E-03	3.2291E-01	1.71
2	2.9813E-01	4.92E-04	2.9872E-01	-1.20
3	2.1885E-01	2.27E-04	2.1940E-01	-2.41
4	1.0946E-01	1.60E-04	1.0962E-01	-0.98
5	5.7382E-02	1.30E-04	5.7522E-02	-1.08
6	5.2392E-02	1.56E-04	5.2488E-02	-0.61
7	2.7904E-02	1.60E-04	2.7838E-02	0.41
8	2.7338E-02	2.13E-04	2.7349E-02	-0.05
9	1.4059E-02	1.16E-04	1.4023E-01	3.14

* One standard deviation of the mean

Table 6

EBR COR1 P0 Scattering Cross Sections (Inelastic + Elastic Combined)

		VIM	Relative Error	ISOTXS	(VIM-ISOTXS) /Sigma*
Group 1 to	1	9.0295E-02	2.30E+00%	8.8331E-02	0.97
	2	3.7797E-02	2.31E+00%	3.6839E-02	1.13
	3	1.1479E-02	2.41E+00%	1.1097E-02	1.43
	4	3.2528E-03	2.93E+00%	3.1260E-02	1.38
	5	7.2349E-04	5.58E+00%	6.8746E-04	0.94
	6	1.8592E-04	7.99E+00%	1.8496E-04	0.06
	7	5.6207E-05	1.77E+01%	5.3846E-05	0.25
	8	3.1707E-05	2.72E+01%	1.8567E-05	1.52
	9	1.5853E-05	3.84E+01%	1.0756E-05	0.84
Group 2 to	2	1.2897E-01	4.89E-01%	1.2868E-01	0.46
	3	2.6442E-02	5.14E-01%	2.6414E-02	0.21
	4	5.6675E-03	5.21E-01%	5.6620E-03	0.19
	5	1.1876E-03	8.08E-01%	1.1979E-03	-1.06
	6	2.2443E-04	1.32E+00%	2.2455E-04	-0.04
	7	3.5126E-05	3.19E+00%	3.4548E-05	0.52
	8	5.9444E-06	1.01E+01%	5.1973E-06	1.24
	9	1.7043E-06	1.56E+01%	1.7924E-06	-0.31
Group 3 to	3	1.6659E-01	3.56E-01%	1.6684E-01	-0.42
	4	1.4554E-02	3.81E-01%	1.4554E-02	0.00
	5	1.6181E-03	5.99E-01%	1.6145E-03	0.37
	6	2.1882E-04	1.10E+00%	2.1903E-04	-0.09
	7	8.1639E-05	1.32E+00%	8.0232E-05	1.33
	8	1.5882E-05	3.35E+00%	1.6281E-05	-0.73
	9	4.1401E-06	6.92E+00%	3.9568E-06	0.67
Group 4 to	4	2.0363E-01	4.07E-01%	2.0350E-01	0.16
	5	8.2816E-03	4.48E-01%	8.2579E-03	0.64
	6	1.6991E-04	1.86E+00%	1.7229E-04	-0.74
	7	2.1659E-05	2.92E+00%	2.2534E-05	-1.33
	8	3.4245E-06	8.44E+00%	3.0624E-06	1.25
	9	6.2264E-07	1.90E+01%	5.1259E-07	0.93
Group 5 to	5	2.3214E-01	6.96E-01%	2.3212E-01	0.01
	6	6.0152E-03	7.67E-01%	6.0135E-03	0.04
	7	1.0139E-04	1.43E+00%	1.0428E-04	-1.94
	8	6.5588E-06	7.47E+00%	6.8063E-06	-0.49
	9	1.0992E-06	1.78E+01%	1.1386E-06	-0.19
Group 6 to	6	2.9918E-01	1.52E+00%	2.9860E-01	0.13
	7	6.3289E-03	1.57E+00%	6.3285E-03	0.00
	8	3.8908E-05	6.58E+00%	3.5733E-05	1.24
	9	4.4236E-06	1.35E+01%	4.2701E-06	0.27
Group 7 to	7	3.0304E-01	1.29E+00%	3.0199E-01	0.27
	8	5.4124E-03	1.42E+00%	5.3476E-03	0.85
	9	5.1520E-05	6.85E+00%	5.1543E-05	-0.01
Group 8 to	8	4.9201E-01	3.44E+00%	4.9077E-01	0.07
	9	1.1947E-02	3.51E+00%	1.1796E-02	0.36
Group 9 to	9	5.9673E-01	3.14E+00%	5.9697E-01	-0.01

* Sigma = one standard deviation of the mean

Table 7

EBR SSTRR P0 Scattering Cross Sections (Inelastic + Elastic Combined)

		VIM	Relative Error	ISOTXS	(VIM-ISOTXS) /Sigma*
Group 1 to 1		1.4689E-01	3.72E+00%	1.4493E-01	0.36
	2	7.4315E-02	3.95E+00%	7.4879E-02	-0.19
	3	2.2781E-02	4.67E+00%	2.2604E-02	0.14
	4	6.2100E-03	5.59E+00%	6.2533E-03	-0.12
	5	1.5375E-03	7.00E+00%	1.5640E-03	-0.24
	6	4.7835E-04	1.77E+01%	5.5398E-04	-0.89
	7	2.3917E-04	1.70E+01%	2.0130E-04	0.93
	8	1.0250E-04	2.25E+01%	7.1193E-05	1.39
	9	3.4168E-05	4.60E+01%	4.1425E-05	-0.36
Group 2 to 2		1.8421E-01	9.57E-01%	1.8412E-01	0.05
	3	4.4708E-02	9.45E-01%	4.4880E-02	-0.41
	4	5.9416E-03	1.04E+00%	5.9462E-03	-0.07
	5	1.3014E-03	1.36E+00%	1.2929E-03	0.48
	6	2.8877E-04	2.44E+00%	2.9636E-04	-1.05
	7	6.6489E-05	3.93E+00%	6.4362E-05	0.84
	8	9.6762E-06	1.18E+01%	1.0690E-05	-0.80
	9	4.2852E-06	1.65E+01%	4.0599E-06	0.34
Group 3 to 3		1.9350E-01	5.80E-01%	1.9359E-01	-0.08
	4	1.5333E-02	5.67E-01%	1.5360E-02	-0.31
	5	1.7630E-03	7.54E-01%	1.7556E-03	0.56
	6	3.1055E-04	1.25E+00%	3.1202E-04	-0.38
	7	1.9803E-04	1.42E+00%	2.0216E-04	-1.44
	8	3.9925E-05	3.04E+00%	4.1291E-05	-1.09
	9	9.3789E-06	5.16E+00%	1.0042E-05	-1.28
Group 4 to 4		2.1959E-01	6.04E-01%	2.1950E-01	0.07
	5	8.8108E-03	6.16E-01%	8.8260E-03	-0.28
	6	2.8537E-05	2.20E+00%	2.9722E-05	-1.81
	7	4.5435E-06	5.05E+00%	4.8550E-06	-1.36
	8	7.5978E-07	1.11E+01%	8.2818E-07	-0.81
	9	1.8235E-07	2.81E+01%	2.2407E-07	-0.81
Group 5 to 5		2.4166E-01	6.95E-01%	2.4130E-01	0.21
	6	8.6127E-03	7.25E-01%	8.6140E-03	-0.02
	7	9.5078E-06	4.51E+00%	1.0223E-05	-1.67
	8	1.2711E-06	1.21E+01%	1.4442E-06	-1.13
	9	1.8643E-07	3.09E+01%	1.1929E-07	-1.82
Group 6 to 6		4.0342E-01	9.17E-01%	4.0280E-01	0.17
	7	1.3152E-02	9.59E-01%	1.3110E-02	0.33
Group 7 to 7		3.3840E-01	1.01E+00%	3.3870E-01	-0.09
	8	1.1822E-02	1.01E+00%	1.1840E-02	-0.15
	9	1.4391E-04	1.87E+00%	1.4316E-04	0.28
Group 8 to 8		9.3145E-01	1.08E+00%	9.3180E-01	-0.03
	9	3.2544E-02	1.10E+00%	3.2460E-02	0.24
Group 9 to 9		7.3505E-01	1.01E+00%	7.3510E-02	-0.01

* One standard deviation of the mean

Table 8

EBR COR1 P1 Scattering Cross Sections (Inelastic + Elastic Combined)

			VIM	Relative Error	ISOTXS	(VIM-ISOTXS) /Sigma*
Group	1 to	1	2.8610E-02	2.51E+00%	2.8200E-02	0.58
		2	4.1621E-05	2.98E+02%	2.7335E-04	0.12
Group	2 to	2	3.7150E-02	4.79E-01%	3.7140E-02	0.06
		3	-9.4358E-04	2.23E+00%	-9.4506E-04	0.07
Group	3 to	3	4.8532E-02	3.58E-01%	4.8780E-02	-1.42
		4	-1.7747E-03	6.75E-01%	-1.7762E-03	0.13
Group	4 to	4	3.3507E-02	4.23E-01%	3.3613E-02	-0.75
		5	-1.9912E-03	7.15E-01%	-1.9781E-03	-0.93
Group	5 to	5	1.9284E-02	8.17E-01%	1.9340E-02	-0.35
		6	-1.4303E-03	8.82E-01%	-1.4250E-03	-0.42
Group	6 to	6	1.4319E-02	1.87E+00%	1.4286E-02	0.12
		7	-1.8383E-03	1.79E+00%	-1.8492E-03	0.33
Group	7 to	7	7.1946E-03	2.22E+00%	7.3514E-03	-0.96
		8	-1.7116E-03	1.77E+00%	-1.7008E-03	-0.36
Group	8 to	8	1.1727E-02	5.67E+00%	1.2069E-02	-0.50
		9	-3.6145E-03	4.05E+00%	-3.5752E-03	-0.27
Group	9 to	9	1.1829E-02	5.30E+00%	1.1231E-02	1.00

* One standard deviation of the mean

Table 9

EBR SSTRR P1 Scattering Cross Sections (Inelastic + Elastic Combined)

			VIM	Relative Error	ISOTXS	(VIM-ISOTXS) /Sigma*
Group	1 to	1	4.8336E-02	3.75E+00%	4.6800E-02	0.88
		2	1.1165E-03	3.44E+01%	1.0667E-03	0.14
Group	2 to	2	5.4919E-02	1.00E+00%	5.5000E-02	-0.15
		3	-2.8461E-03	1.36E+00%	-2.9247E-03	1.98
Group	3 to	3	4.2349E-02	6.17E-01%	4.2473E-02	-0.47
		4	-2.6513E-03	6.49E-01%	-2.6724E-03	1.22
Group	4 to	4	2.4037E-02	6.42E-01%	2.4061E-02	-0.16
		5	-1.3830E-03	8.91E-01%	-1.3899E-03	0.56
Group	5 to	5	1.3867E-02	7.31E-01%	1.3880E-02	-0.13
		6	-2.6027E-03	7.73E-01%	-2.6177E-03	0.74
Group	6 to	6	2.1136E-02	9.39E-01%	2.1142E-02	-0.03
		7	-4.2649E-03	1.02E+00%	-4.2453E-03	-0.45
Group	7 to	7	9.4428E-03	1.29E+00%	9.4288E-03	0.12
		8	-3.2815E-03	9.56E-01%	-3.2949E-03	0.43
Group	8 to	8	2.5464E-02	1.33E+00%	2.5484E-02	-0.06
		9	-1.0230E-02	1.15E+00%	-1.0200E-02	-0.26
Group	9 to	9	1.0334E-02	1.16E+00%)	1.0308E-02	0.22

* One standard deviation of the mean

Table 10

EBR COR1 P0 N2N Cross Sections

		VIM	Relative Error	ISOTXS	(VIM-ISOTXS) /Sigma*
Group 1 to	1	1.4412E-06	1.00E+02%	8.486 E-06	-4.9
	2	5.3181E-04	6.09E+00%	5.0349E-04	0.92
	3	1.5479E-03	3.73E+00%	1.5385E-03	0.17
	4	1.2409E-03	3.76E+00%	1.2130E-03	0.61
	5	4.0930E-04	7.72E+00%	3.8771E-04	0.70
	6	8.5032E-05	1.45E+01%	7.4667E-05	0.84
	7	4.3236E-06	5.46E+01%	4.5177E-06	-0.08
	8	0.0		4.6304E-07	
	9	0.0		7.8623E-08	
Group 2 to	2	0.0		1.3784E-08	
	3	7.8981E-07	1.79E+01%	6.3650E-07	1.08
	4	2.3279E-06	1.23E+01%	2.0119E-06	1.10
	5	1.7043E-06	1.44E+01%	1.3910E-06	1.28
	6	3.3255E-07	2.81E+01%	4.4324E-07	-1.18
	7	8.3138E-08	6.88E+01%	9.3137E-08	-0.17
	8	0.0		1.4734E-08	
	9	0.0		1.1656E-09	

* One standard deviation of the mean

Table 11

EBR SSTRR P0 N2N Cross Sections

		VIM	Relative Error	ISOTXS	(VIM-ISOTXS) /Sigma*
Group 1 to	1	0.0		5.2429E-07	
	2	3.4168E-05	4.60E+01%	5.4966E-05	-1.32
	3	9.3961E-05	2.80E+01%	9.5534E-05	-0.06
	4	2.5626E-05	5.47E+01%	4.0961E-05	-1.10
	5	1.7084E-05	6.89E+01%	1.4530E-05	0.26
	6	0.0		4.6216E-06	
	7	0.0		1.5575E-06	
	8	0.0		5.7254E-07	
	9	0.0		3.3299E-07	

* One standard deviation of the mean

Table 12

Test Problem Reference Datasets

Test	File Type	File Sys.	File Name
1	vim input	RANetwork	~b24366/vim/test/2gmg.aniso/VIMINPT
	ISOTXS	RANetwork	~b24366/vim/test/2gmg.aniso/ISOTXS
	source site generator (FORTRAN)	RANetwork	~b24366/vim/test/2gmg.aniso/make.hetc.sites
	isovim input	RANetwork	~b24366/vim/test/2gmg.aniso/isovim.in
	twodant aniso. deck	RANetwork	~b24366/vim/test/2gmg.aniso/twodant.s16.aniso.deck
	twodant iso. deck	RANetwork	~b24366/vim/test/2gmg.aniso/twodant.s16.iso.deck
2	vim input	RANetwork	~b24366/vim/test/VIMINPT10
	isovim input	RANetwork	~b24366/vim/test/finck.isoin
	isotxs	RANetwork	~b24366/vim/test/finck.ISOTXS
	DIF3D job deck	RANetwork	~b38420/rundir/ebr3d
	DIF3D input	RANetwork	~b38420/rundir/ebr3d.job
3	ISOTXS	MVS	$B29809.HTGR.GR10.ISOTXS
4	ISOTXS	MVS	$B24366.PU239.ISOTXS

Table 13

Angular Mesh Effects
Group 1 Elastic Scattering in Material CORE (Ref 15)

Order	ISOTXS cross section	(VIM-ISOTXS)/ISOTXS(%) (20 intervals)	(VIM-ISOTXS)/ISOTXS(%) (100 intervals)
P0	1.950356-1	-0.0029 +/- 0.086	0.0023 +/- 0.098
P1	5.172684-2	-0.57 +/- 0.099	0.0003 +/- 0.099
P2	3.385031-2	-1.36 +/- 0.098	-0.036 +/- 0.10
P3	1.988164-2	-4.28 +/- 0.12	-0.14 +/- 0.12